IN THE

Supreme Court of the United States

OCTOBER TERM, 1975

No. 75-1589

ALCOR AVIATION, INC.,

Petitioner,

versus

RADAIR INCORPORATED,

Respondent.

SUPPLEMENTAL APPENDIX FOR PETITION FOR A WRIT OF CERTIORARI TO THE UNITED STATES COURT OF APPEALS FOR THE NINTH CIRCUIT

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RECIPROCATING-PISTON GASOLINE ENGINE FUEL-AIR RATIO CONTROL

Filed Nov. 5, 1962 2 Sheets-Sheet 1

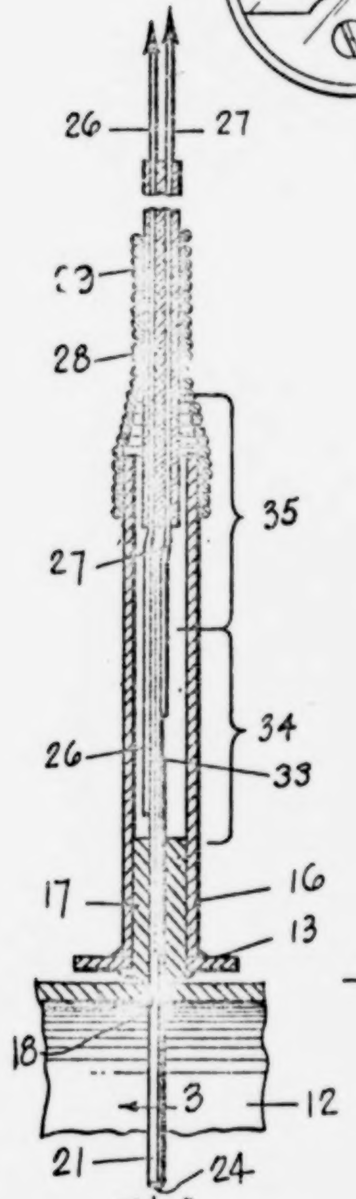

Fig. 2

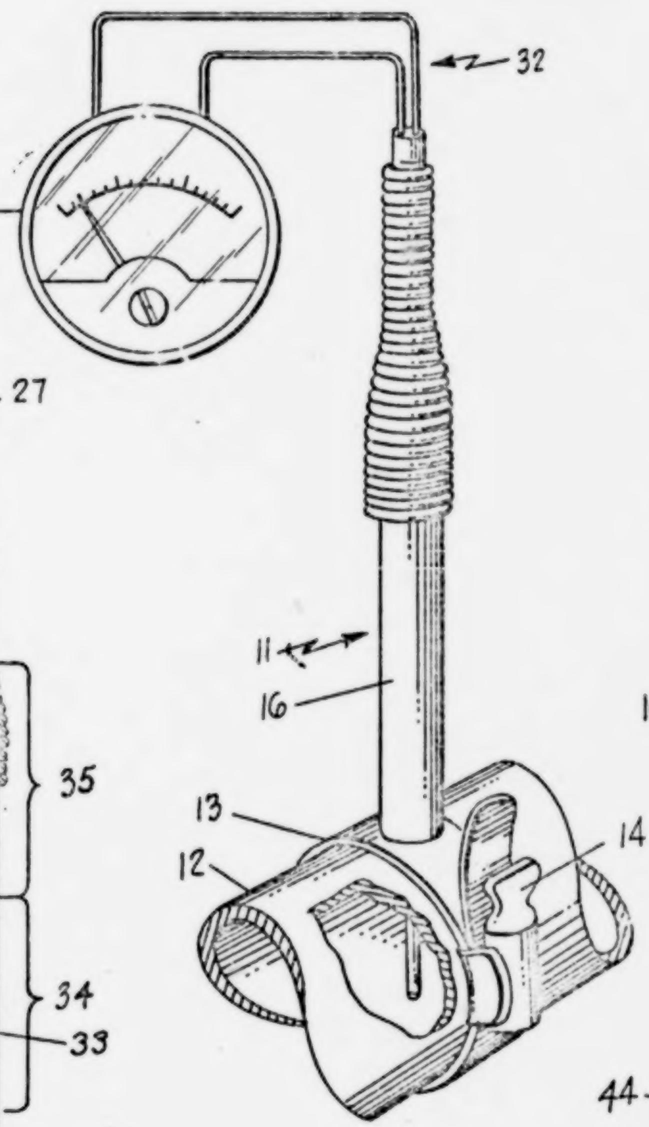

Fig. 1

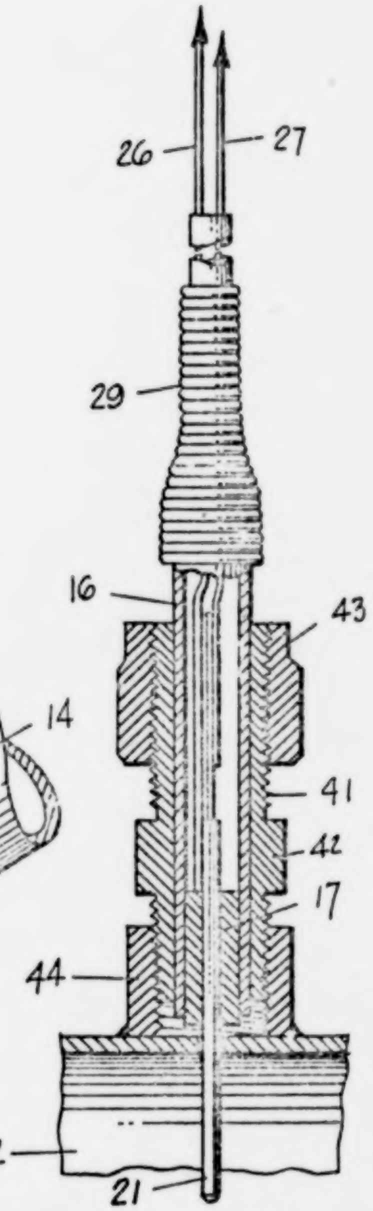

Fig. 4

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Oct. 27, 1964 A. HUNDERE 3,154,060

RECIPROCATING-PISTON GASOLINE ENGINE FUEL-AIR RATIO CONTROL

Filed Nov. 5, 1962 2 Sheets-Sheet 2

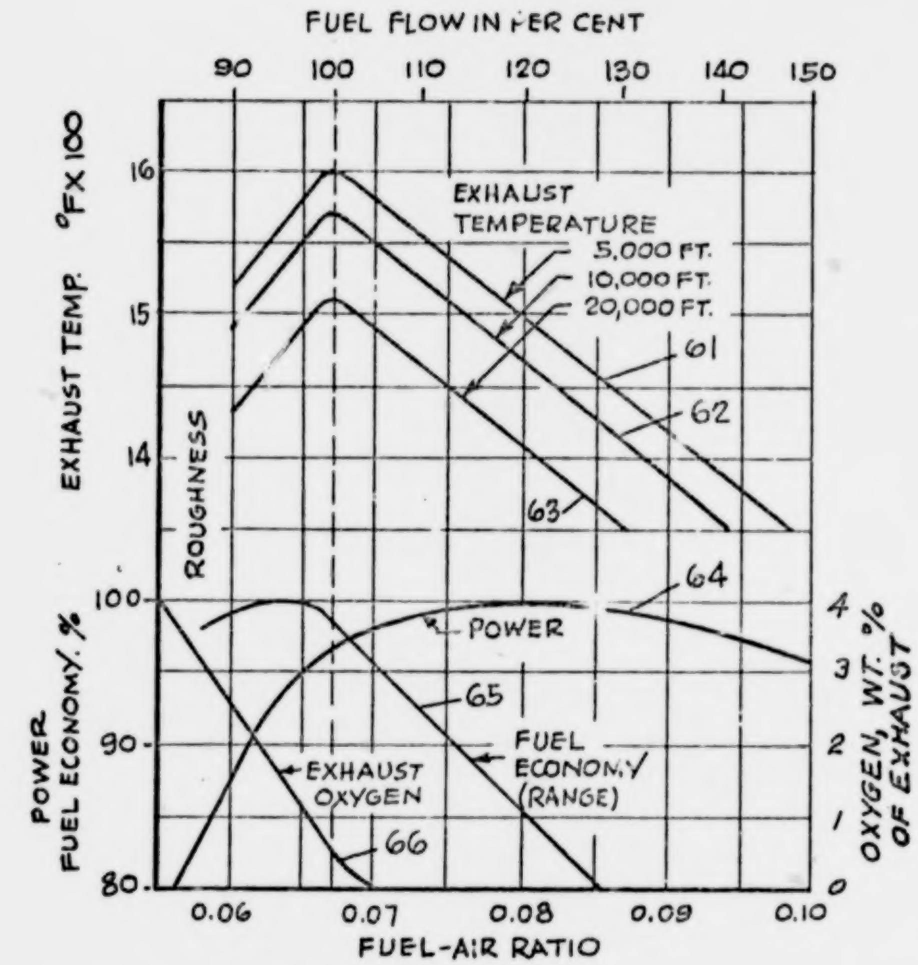

Fig. 6

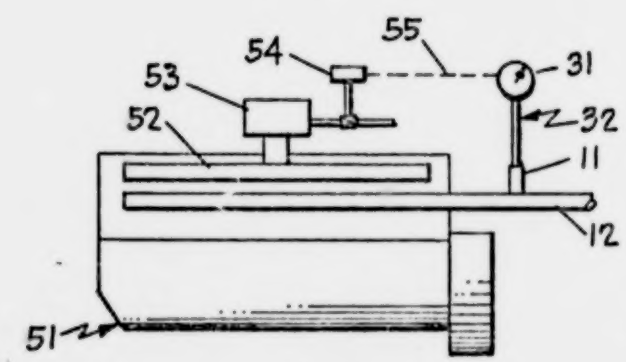

Fig. 5

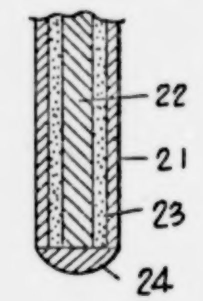

Fig. 3

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RECIPROCATING-PISTON GASOLINE ENGINE FUEL-AIR RATIO CONTROL

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Filed Nov. 5, 1962, Ser. No. 235,430
6 Claims. (Cl. 123—119)

The present invention relates to the control of the fuel air ratio of reciprocating piston gasoline engines. In more particular, the invention relates to a combination of such an engine, its fuel-air ratio adjustment means, and an exhaust gas temperature sensor and indicator for sensing and indicating the temperature of such engine's exhaust gas under operating conditions so that the operator can control the fuel-air ratio in accordance with such indications. Further, the present invention relates to the construction of such sensing and indicating means having such a sensitivity and speed of response that the operator can adjust the fuel-air ratio in a sufficiently short time as needed for improved operation of the engine.

Also, the invention relates to a new method of adjusting the fuel-air ratio of reciprocating piston gasoline engines in accordance with sensitive and rapid indications of the exhaust gas temperature of the engine, and more particularly relates to such a method in which the fuel-air ratio is adjusted in accordance with an indication of the maximum exhaust temperature obtainable by an adjustment of the fuel-air ratio.

In the operation of airplanes not equipped with altitude compensated carburetors, which constitute the vast majority of airplanes in the general aviation category, the fuel-air ratio is controlled in the same manner as on the Model T Ford, that is, manually as a result of the feel and sound of engine operation for the indication of the best mixture of fuel and air. This wastes fuel which on the average, amounts to at least 10% of the fuel used, and, in some cases, it is considerably more. Safety is jeopardized because a mixture that is too lean can cause engine failure from burned valves, and, because, when the mixture is set too rich, as is a common occurrence for a pilot who does not have the proper mixture setting feel, unscheduled landings and crashes can result from the fuel consumption exceeding that anticipated. It has always been recognized that a mixture indicator is needed to eliminate guessing. Exhaust gas analyzers such as the Cambridge analyzer have been available for twenty years or more. These analyzers require a sensing element that responds to change in exhaust gas composition, but these elements are prone to being poisoned by lead from the fuel and other contaminants. The result is that reliability is poor and the maintenance is extremely high. In addition, they have slow response and a very high initial cost. The need for changing settings of the fuel-air adjustment means, in addition to an initial setting, derives from the varying conditions under which an airplane is operated and the need for an optimum fuel-air ratio under each such condition, which ratio is different for each such condition. Such varying conditions are those of power demand and changes in temperature and pressure due either to daily variations or change in altitude.

The present invention particularly further relates to a thermoelectric junction, particularly a hot or temperature sensing junction of a thermocouple having a high sensitivity because of its low thermal inertia and high rate of change in electromotive force (E.M.F.) with change in temperature, together with high resistance to corrosion at elevated temperatures, particularly at the exhaust temperatures of reciprocating piston gasoline engines, such as the range of 1400° F. to 1700° F. An important purpose of the present invention is the development of a thermoelectric temperature sensing junction, a thermo-

couple probe, that can be used to sense the exhaust temperature changes of reciprocating piston gasoline engines as an aid in fuel-air ratio adjustment for needed engine operation. Such a use requires a fast response to temperature changes, that is, the hot junction probe of the thermocouple must have low thermal inertia. In addition, it must have high output per unit temperature change, millivolts per ° F., in order to obtain high sensitivity. Of available thermocouple materials, Chromel-constantan gives the maximum output per unit temperature change, 45 millivolts per ° F. as compared to 23 millivolts per ° F. for Chromel-Alumel, the conventional thermocouple material for exhaust gas temperature measurement. Constantan, however, can not be exposed to exhaust temperatures without excessive corrosive oxidation. If the Chromel-constantan thermocouple is encased in a protective sheath, such as stainless steel, the mass is increased to thereby increase the thermal inertia. If the constantan is located in a sheath, air must be excluded from entering inside the sheath because at exhaust temperatures the constantan readily oxidizes.

Accordingly, an object of the present invention is the devising of a fuel-air ratio control system for reciprocating piston gasoline engines including an exhaust gas temperature sensor and indicator with negligible lag so that optimum ratios may be obtained and maintained with such speed and sensitivity as to enable improved operation of the engine.

More specifically, it is an object to make a Chromel-constantan thermocouple which will have small mass, hence, low thermal inertia, and high resistance to corrosion.

Also, it is an object of the invention to devise a thermocouple in which a constantan metal portion of the hot junction is protected against corrosion by a Chromel portion of the thermocouple.

It is a further object to devise a thermocouple in which the least corrosive of the two metallic elements of a thermocouple is used to protect the other from contact with a corrosive environment.

Another object of the invention is to devise a thermocouple that has low thermal inertia, high change in E.M.F. per unit temperature change, and resistance to corrosion.

In accordance with a preferred embodiment of the invention, the above-mentioned defects of the prior art fuel-air ratio control systems and thermocouples are remedied and the above objects achieved by the construction of a thermocouple's electrodes in which a Chromel part, or electrode, surrounds and seals a constantan part, or electrode, against corrosion by the use of a constantan wire coaxial of a Chromel sleeve and with wire and sleeve electrically insulated from each other by a refractory material such as magnesia. The contact, the hot junction, the actual Chromel-constantan junction, is formed at the adjacent free ends of the electrodes by fusion thereof by the use of a helium shielded arc using a Chromel electrode or other metal having sufficient corrosion resistance. This insulation is compacted by swaging or drawing the sleeve, and the inboard end of the sleeve is sealed to the core by means of a high temperature sealant. Leads to a meter circuit are joined to the electrodes at their inboard ends. The hot junction and the adjacent lengths of the electrodes constitute a probe which may be inserted in a medium for temperature determinations, when such junction and electrodes are connected in a proper meter circuit.

Embodiments of the device described briefly above are hereinafter described in detail and illustrated in the accompanying drawings, in which:

FIGURE 1 is a perspective view of one form of the

invention as applied to a section of an engine exhaust pipe with parts of the pipe cut away.

FIGURE 2 is a longitudinal sectional view of FIGURE 1.

FIGURE 3 is an enlarged longitudinal sectional view of the hot junction of either FIGURE 2 or 4 but shown as taken on the line 3—3 of FIGURE 2.

FIGURE 4 is a longitudinal sectional view of a modification of the invention.

FIGURE 5 is a diagramatic showing of the disclosed fuel-air ratio control system applied to an engine.

FIGURE 6 is a showing of curves useful in an understanding of the present invention.

In the showing of FIGURES 1, 2 and 3, a thermocouple assembly **11** is shown as formed so that it may be removably clamped to an engine exhaust pipe **12** by means of a steel strap **13** arranged circumferentially of the pipe, the strap having a screw means **14** for tightening the strap and the thermocouple assembly to the pipe **12**. The strap is welded to one end, the lower end, of a tube **16** around an opening in the strap, and to an axially bored stainless steel plug **17** in the lower open end of the tube **16**. The lower end of the plug **17** is coned so as to fit in and close an opening **18** in the exhaust pipe **12**, the plug being positioned and held in the opening by the strap **13** being tensioned around the pipe.

Sealed in the axial bore of the plug **17** is a Chromel metal sleeve **21**. This sleeve extends from the lower ends of the plug and tube a distance which will locate the lower end of the sleeve a desired distance into the exhaust pipe **12**. Inside of the Chromel sleeve **21** is a constantan wire **22** that has its lower end flush with the lower end of the sleeve. The constantan wire is smaller in diameter than the inside of the sleeve, and the sleeve and the wire are spaced and electrically insulated from each other by packing the space there between with a high temperature electrical insulating material, such as powdered magnesia **23**, as this insulating material must continue to function at temperatures in the region of 1700° F. The hot junction element **24**, see FIGURE 3, between the Chromel sleeve **21** and the constantan core **22**, or wire, is formed by a weld that covers and bonds to the end of the wire **22**, bridges the end opening between the wire and the sleeve **21**, and bonds to the sleeve to seal such end opening. This weld, or junction element **24**, is made with a helium shielded arc using a Chromel electrode or a metal having sufficient corrosion resistance. Thus the constantan is sealed from contact with the exhaust gases of the exhaust pipe **12** and there is formed between the Chromel and the constantan a thermoelectric junction. Further, the magnesia powder **23** between the sleeve **21** and the wire **22** insulates them so that contact there between is limited to the outer end junction element **24**.

The upper end of the sleeve **21** extends above the plug **17** a short distance, the wire **22** extends a short distance above the upper end of the sleeve, and the tube **16** extends well above the upper end of the wire. A Chromel lead wire **26** is welded to the Chromel sleeve, and a constantan lead wire **27** is welded to the constantan wire **22**. The Chromel and constantan lead wires are protected by a surrounding insulating material **28**, and the insulated wires and insulation **28** are protected and supported by means of a spiral spring retainer **29** that resiliently grips the exteriors of both the insulator **28** and the tube **16**. The Chromel and constantan electrodes **21**, **22**, their junction **24**, and the two conductors **26**, **27**, and a millivoltmeter **31** are in a circuit **32**. The meter functions so that its indicating range is, preferably, substantially between 1200° F. and 1700° F. The meter is supplied with an electric voltage bucking the voltage obtained from the thermocouple so that the meter does not operate until the beginning of the desired temperature range of indication, for example, 1200° F. to 1700° F. or is supplied

with mechanical suppression obtained by adjustment of the meter spring to obtain such range of indication.

Swaging or drawing of the sleeve **21** after insertion of the wire **22** and the magnesia **23**, packs the magnesia **23** therein. Preferably, the swaging or drawing is so done that the sleeve retains its circular cross section upon reduction of diameter. This is a step in the manufacture of this device that substantially excludes the entrance of air into the sleeve with a resulting reduction in the corrosion of the constantan wire. The addition of high temperature sealant **33** of an electrical insulating type between the upper end of the Chromel sleeve **21** and the constantan wire **22** gives positive assurance that air will not enter the sleeve **21** to contact the constantan wire **22** in the area that it has oxidizive temperatures. The inside of the tube **16** above the lower end-plug **17** is filled with a high temperature insulating material **34** such as magnesia cement, represented by the bracket carrying the reference number **34**. This material extends upward in the tube **16** about three quarters of the distance from the plug **17** to the top of the tube **16**. Inside the tube **16** above the insulating material **34** and inside the spring retainer **29** there is placed a high temperature epoxy cement **35** represented by the bracket carrying the reference number **35**. This cement retains in place the insulator **28** and the lead wires **26**, **27**.

In the modification of FIGURE 4, those parts which are the same or substantially the same as those shown in FIGURES 1, 2 and 3 have been given the same reference numerals as those found and used in such figures. In FIGURE 4, the tube **16** above the plug **17** is filled with insulating material such as magnesia **34** and epoxy cement **35** in the same manner as in the previously described form of the invention. The tube **16** has a slip fit with clamping ferrule **41** that has a wrench boss **42** formed medially thereof with the peripheral portions adjacent each and having tapered threads thereon. The lower end of the tube **16** extends slightly beyond the lower end of the ferrule **41**, and the upper end of the ferrule is spaced from and below the retainer spring **29**. The ferrule **41** is clamped to the tube **16** by a clamp ring **43** that surrounds the tube adjacent its upper end and is internally threaded to match the taper threads of the ferrule. Turning the ring down on the ferrule effects the clamping of the ferrule to the tube. The lower end of the ferrule is screwed into the matching internal threads of a ring boss **44** that is welded to the exhaust pipe **12**. The Chromel sleeve **21** and the constantan core wire **22** extend into the exhaust pipe through the hole **18** in the pipe which is coaxial of the ring boss **44**.

By the construction of either of the described embodiments, the exhaust probe may be easily positioned as shown and removed from such position for servicing. The thermocouple assembly **11** and its circuit **32** are designed to indicate the temperature of the exhaust gases in the exhaust pipe **12** when the fuel-air mixture is varied for the engine with which the exhaust pipe is associated.

While the present disclosure is particular to the use of Chromel as the metal electrode sleeve and constantan as the metal electrode wire, the disclosed construction is applicable to the utilization of other electrode metals for the formation of the hot junction of a thermocouple. Such metals are well known in the art and handbooks. The present invention relates to a construction whereby one metal of a thermocouple may be sealed against corrosion in a simple manner that, also, produces a thermocouple probe of a small mass. This construction, further, results in a thermocouple of high E.M.F. usable at high temperature.

FIGURE 5 is a diagrammatic showing of the disclosed fuel-air ratio control system applied to an engine **51** having an intake manifold **52** which is supplied with a fuel-air mixture from a carburetor **53** having a fuel-air ratio adjustment means **54** which is responsive through a control **55**, manual or otherwise, to the temperature

indications of the meter 31 placed in the circuit 32 with the thermocouple assembly 11 that has its probe in the exhaust pipe 12 of the engine 51. By means of the above system, indications of engine exhaust temperature and temperature changes are directly usable to set the fuel-air ratio of the carburetor 53 and of the mixture being supplied to the engine, and to set and maintain such ratio at optimum values as such values change due to changes in engine operation. Such values are maintained because of the disclosed construction.

An understanding of the relationship between exhaust temperature and fuel-air ratio of a gasoline reciprocating-piston engine may be had from a consideration of the curves of FIGURE 6. These curves show the relationship between fuel-air ratio plotted as abscissa; against exhaust temperature at altitudes of 5,000 feet, curve 61, at 10,000 feet, curve 62, and at 20,000 feet, curve 63; against power, curve 64; against fuel economy, curve 65; and against exhaust oxygen, curve 66.

All of the exhaust temperature curves have sharp peaks, and all of these peaks occur at the same fuel-air ratio value, which is the stoichiometric weight ratio of 0.067 for the average gasoline. With the negligible lag between temperature changes in the exhaust and their indication on the meter, it is possible to set the fuel-air mixture by reference to a temperature indication. From the practical standpoint, there are only two fuel-air mixtures that are important in the operation of a reciprocating-piston gasoline engine, best power and maximum economy. It will be noted from curves 61, 62, 63 and 64 of FIGURE 6 that best power occurs when the fuel-air mixture is enriched to cause about a 100° F. drop in exhaust temperature from the peak. At maximum exhaust temperature mixture, the fuel economy is close to maximum (as shown by curve 65) and is considered optimum for cruise operation of unsupercharged engines because at leaner mixtures the power drops off too rapidly. For a supercharged engine where the airflow can be increased to compensate for the drop in power with mixture leaning, the optimum cruise mixture is on the lean side of the exhaust temperature peak by an amount to give approximately a 25° F. drop from the peak. The maximum leaning that is permissible is a function of the uniformity of the fuel distribution among the individual cylinders; the poorer the fuel distribution the closer the point of roughness approaches the peak exhaust temperature. The data in FIGURE 6 is for an engine with good fuel distribution. For an engine with poor fuel distribution, the point of roughness would approach and might reach the point of maximum exhaust temperature.

In FIGURE 6, the curve 66 has the ordinal values shown on the right hand side of the figure as weight percent of oxygen in the exhaust gas. It is desirable to keep the oxygen low in the exhaust to reduce the tendency of the exhaust valves to burn.

In the use of this invention for obtaining the desired fuel-air ratio, while the reciprocating-piston gasoline engine is operating under constant conditions, the mixture is slowly changed, normally from rich to lean, until a peak meter reading is observed. The mixture control is then adjusted to the peak temperature observed if optimum mixture for cruise is desired or is adjusted to enrich the mixture to lower the temperature about 100° F. from the peak temperature if best power is desired. The mixture cannot, however, be leaned to give peak exhaust temperature at power output levels which will give engine detonation, such as may take place at full throttle at sea level.

The relationship between fuel-air ratio and exhaust temperature shown in FIGURE 6 and discussed above holds for all reciprocating-piston gasoline engines for all practical purposes. The fuel-air ratio at which peak exhaust temperature occurs, varies slightly with the carbon-hydrogen ratio of the gasoline, but the maximum economy and best power points remain the same relative to the mixture for peak exhaust temperature.

A specific example of the composition of the Chromel electrode sleeve 21 is: 90% nickel and 10% chromium; and a specific example of the constantan electrode wire 22 is: 60% copper and 40% nickel.

Having thus described my invention, its construction, operation, and use, I claim:

1. A reciprocating-piston gasoline engine, such engine upon operation under constant conditions being characterized by having a maximum exhaust gas temperature that is obtainable by adjustment of the fuel-air ratio of the fuel mixture supplied to such engine during such operation, such engine having in combination therewith a fuel-air ratio control system including a fuel-air ratio adjustment means, and an exhaust gas temperature sensing and indicating means capable of sensing and indicating such exhaust temperature during changes thereof, resulting from manipulation of said adjustment means, so that the time lag of temperature sensing and indication behind temperature change is so small that indication substantially follows change, to enable the fuel-air ratio of said engine to be controlled by setting said ratio adjustment means in accordance with the indications of said indicating means during such operation and change in such ratio.

2. The combination of claim 1 in which such indications delineate such maximum temperature and such settings are made to give indications in predetermined relationship to such maximum.

3. The method of controlling the fuel-air ratio of a reciprocating-piston gasoline engine having, for the fuel mixture supplied thereto, a fuel-air ratio control system with manually operable means for adjustment of such ratio, such engine upon operation under constant conditions being characterized by having a maximum exhaust gas temperature that is obtainable by manual adjustment of said manually operable means, which method comprises: operating such an engine under constant conditions, while such engine is so operating, manually operating said means for adjustment of such ratio to vary such ratio so as to effect a determination of such maximum temperature, and manually setting said manually operable means in accordance with such determination.

4. The method of controlling the fuel-air ratio of a reciprocating-piston gasoline engine having, for the fuel mixture supplied thereto, a fuel-air ratio control system with manually operable means for adjustment of such ratio between a ratio leaner than and a ratio richer than the stoichiometric ratio, such engine upon operation under constant conditions being characterized by having a maximum exhaust gas temperature that is obtainable by manual adjustment of said manually operable means, and having an exhaust gas temperature sensing and visually indicating means capable of sensing and visually indicating such exhaust temperature during changes thereof resulting from manual adjustment of said manually operable means, the time lag of temperature sensing and indication behind temperature change being so small that indication substantially follows change, which method comprises: operating such an engine under constant conditions, while such engine is so operating, manually operating said means for adjustment of such ratio to vary such ratio and visually observing said indicating means while so varying such ratio so as to correlate such manual operation with such observations to effect indications of temperature rise and fall as the ratio is varied either from rich to lean or from lean to rich, such observations including determination of the maximum temperature indication, and then manually setting said means for adjustment to give a visual indication of an exhaust temperature having a predetermined relationship to such maximum temperature indication.

5. The method of controlling the fuel-air ratio of a reciprocating-piston gasoline engine having a system for varying the fuel-air ratio of the fuel mixture supplied to such engine to obtain ratios between ratios leaner and richer than the stoichiometric ratio, such engine upon operation under constant conditions, except for variations in its fuel-air ratio, being characterized by having a maximum exhaust gas temperature that is obtainable by adjustment of the fuel-air ratio to the stoichiometric ratio, which method comprises: operating such an engine under constant conditions, while such engine is so operating, determining the substantially instantaneous exhaust gas temperatures of such engine while varying such fuel-air ratio between lean and rich, determining the maximum of such previous determinations, and setting said ratio so that and determining that there is an exhaust gas temperature of a predetermined relative value with respect to such maximum value.

6. The method of claim 4 in which such engine is an airplane engine in flight.

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CERTIFICATION OF SERVICE

I, Ted D. Lee, do hereby certify that true and correct copies of the foregoing Supplemental Appendix for Petition for a Writ of Certiorari to the United States Court of Appeals for the Ninth Circuit have been mailed to Benjamin F. Berry, of Seed, Berry, Vernon & Baynham, 1001 Bank of California Center, Seattle, Washington 98162, counsel for Respondent herein, on this the 7th day of May, 1976.

Ted D. Lee

Ted D. Lee